CODE Contribution to IGS Reprocessing: Status and Perspectives

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Introduction

Since the very beginning, CODE – the Center for Orbit Determination in Europe – is one of the global analysis centers of the International GNSS Service (IGS). CODE is operated by the Astronomisches Institut, Universität Bern (AIUB, Switzerland) in close cooperation with the Bundesamt für Landestopografie (swisstopo, Switzerland), the Bundesamt für Kartographie und Geodäsie (BKG, Germany), and the Institut für Astronomische und Physikalische Geodäsie (IAPG) of Technische Universität München (TUM, Germany). The operational CODE processing is a rigorous multi–GNSS analysis including GPS and GLONASS for all product lines of the IGS since May 2003.

The first CODE reprocessing run covers the time period from January 1994 to December 2008. Although these reprocessing activities are mainly performed by IAPG, full consistency with the modeling setup of the operational CODE processing is realized. About 240 stations are included. According to the IGS guidelines for the current reprocessing effort, the analysis is limited to GPS on the first stage. These results are submitted to the IGS. The GPS-only solution has been extended by the inclusion of the available combined GPS/GLONASS tracking stations at AIUB for the period from June 2003 to December 2008. The resulting products will be made available soon.

Detection of Outliers and Discontinuities

A new program of the Bernese GPS Software called FODITS (Find Outliers and Detect Discontinuities in Time Series, *Ostini et al.*, 2009) was used for the detection of outliers and discontinuities. The functional model of FODITS consists of one or more linear velocities per station, discontinuities, outliers, and a set of periodic functions. For the current analysis, annual, semi-annual, monthly, and semi-monthly periods were estimated. Changes in the station equipment (i.e., antenna, radome, and receiver) as well as earthquakes with a magnitude larger than five were tested for significant discontinuities. Furthermore, discontinuities without any known reason were detected. Outliers are defined based on the RMS of the post-fit residuals and their absolute value.

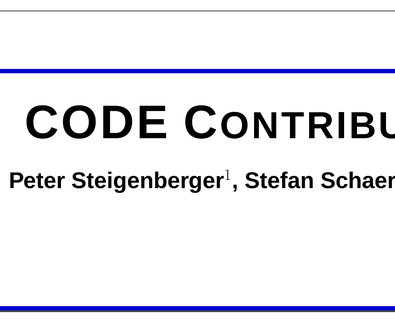

FIGURE 1: Time series of weekly station coordinate residuals for Kokee Park. Four discontinuities have been detected, two other equipment changes (indicated by a small s) did not cause a significant discontinuity. The outliers in the middle of 1996 are related to a degraded tracking performance of the antenna which was replaced in August 1996.

Comparisons With Other Solutions

Station Coordinates

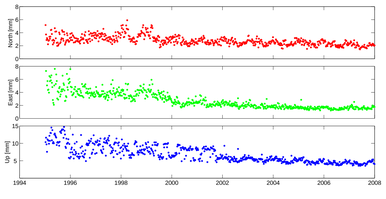

FIGURE 2: Residuals of 7-parameter similarity transformations between weekly solutions of CODE and ESA.

The RMS of 7-parameter similarity transformations between all common stations of the weekly reprocessed solutions of CODE and the IGS analysis center of the European Space Agency (ESA) are shown in Figure 2. Back until 2001, the residuals are on the 2 mm level for the horizontal components and 5 mm for the height. Before 2001, the residuals increase due the decreasing number of stations.

Satellite Orbits

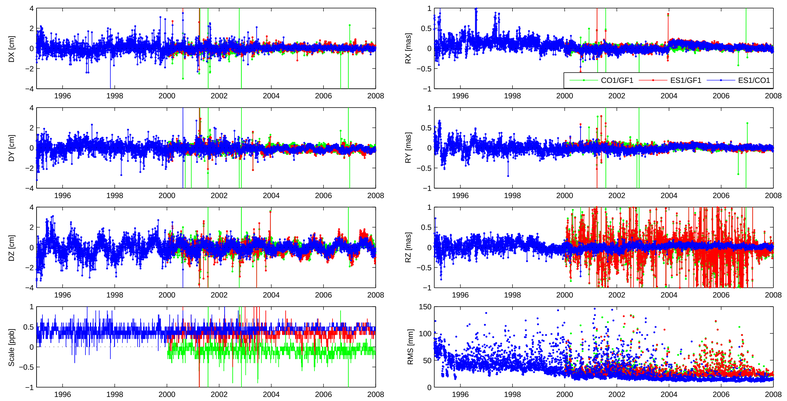

FIGURE 3: Transformation parameters and RMS of 7-parameter similarity transformations between reprocessed orbits of CODE (CO1), the European Space Agency (ES1), and Deutsches GeoForschungsZentrum (GF1).

The transformation parameters and RMS of 7-parameter similarity transformations between the reprocessed orbits of CODE (CO1), the European Space Agency (ES1), and Deutsches GeoForschungsZentrum (GF1) are shown in Figure 3. The most remarkable characteristics are:

- Periodic signal in the z-translation (DZ) visible for all comparisons.
- The scale difference of about 0.4 ppb between ES1 and CO1 as well as ES1 and GF1 is probably related to the application of an Earth albedo model by ESA.
- Shift in the x-rotation (RX) in the beginning of 2004 for both ES1 comparisons, not visible in the CO1/GF1 comparison.
- Quite large z-rotations (RZ) of the GF1 solution compared to CO1 and ES1.
- The reduced RMS values of the CO1/ES1 comparison during three time periods in 1995 are related to the deactivation of anti-spoofing.

"Pre-2000" GPS P1-C1 Bias Values

Monthly P1-C1 bias averages that were computed on the basis of TUM daily reprocessing results (*Steigenberger et al.*, 2006) were made available back to January 1996. For the years 1994 and 1995, yearly averaged bias values were computed on the basis of 1996 monthly mean values, see Figure 4. By this, bias values for three previous PRN numbers (namely G12, G13, G28), or 31 satellite-months remain "undefined". The complete series of CODE/TUM's monthly P1-C1 bias files may be found at `ftp://ftp.unibe.ch/aiub/CODE/yyyy/P1C1yymm.DCB.Z` or, in a compiled, cc2noncc-compatible form, in `ftp://ftp.unibe.ch/aiub/bcwg/cc2noncc/p1c1bias.1994(p)`.

The verified receiver classification (P1/P2, C1/X2=C1+(P2-P1), or C1/P2) is given in CODE's receiver information file (`ftp://ftp.unibe.ch/aiub/BSWUSER50/GEN/RECEIVER`.) for all receiver names that are relevant for the reprocessing at TUM as well as those used for the operational analysis at CODE.

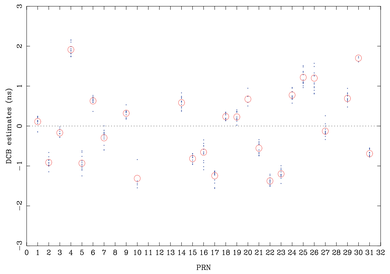

FIGURE 4: Combined and realigned P1-C1 monthly bias results for 1996. The resulting mean bias values were adopted for 1994 and 1995, as pre-1996 bias retrievals turned out to be very noisy.

GLONASS Extension of the CODE Reprocessing

When CODE started the operational multi-GNSS processing in May 2003, the number of combined GPS/GLONASS tracking stations was very limited (usually about 30 sites until end of 2006). As documented in Figure 5, the number of GLONASS tracking stations has significantly increased in the reprocessing effort, in particular in these early years.

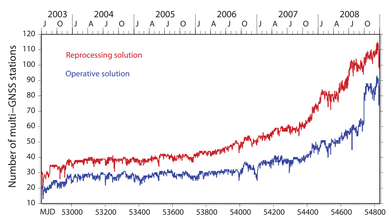

FIGURE 5: Number of sites providing GLONASS data, which were used for orbit determination in the CODE reprocessing (red) and the operational final solution (blue).

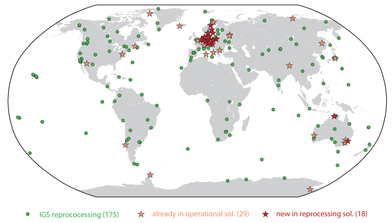

FIGURE 6: Geographical distribution of stations included in the reprocessed solution for 23 August 2006 as a typical example: GPS-only contribution to the IGS reprocessing (green dots) and the GLONASS extension (stars), where we may distinguish between those stations already included in the operational CODE final solution (orange stars) and stations added for the CODE reprocessing solution (red stars).

Unfortunately, most of these additional sites are located in Europe, where already the density of stations used in the operational processing is quite high. The typical distribution of stations before the year 2007 is shown in Figure 6. Due to the inclusion of numerous GLONASS tracking stations, a global distribution has been achieved in the operational solution since the beginning of October 2008. The reprocessed solution has a reasonable global coverage of the GLONASS-capable sites already since the beginning of the year 2008.

The full consistency of the GLONASS orbits with the CODE products submitted to the IGS reprocessing (GPS-only solution) has been achieved by adding a combined GPS/GLONASS solution of all available sites of each day to the GPS-only solution on the normal equation level. The modeling and parametrization is fully consistent. As already reported in *Dach et al.* (2009), there is no significant impact from the additional GLONASS observations neither on the GPS orbits (below 1 cm RMS) nor on the reference frame (below 1 mm RMS in the daily solutions).

The RMS of the GLONASS orbits obtained in this reprocessing effort is significantly improved with respect to the operational CODE solution in particular in the period before 2008: from 8 – 10 cm to about 5 – 6 cm, see Figure 7. In the operational solution of CODE the orbit quality gets better during the year 2008 to a level of 3 – 4 cm due to the further improvement of the global coverage with GLONASS tracking stations. Apart from the GLONASS orbits also an update of the GLONASS satellite antenna phase center model has been computed within this reprocessing effort. These results are the topic of the solicited presentation *The use of system-dependent antenna phase center models in a global multi-GNSS analysis* by Dach et al. in session G4 *GNSS in Geosciences: news and prospects*.

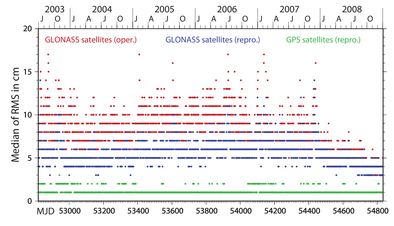

FIGURE 7: Median of the RMS for the fit of a three-day arc through the daily independent orbit solutions for the GLONASS satellites obtained in the CODE reprocessing (blue) and the operational CODE final solutions (red). For comparison the analogue values for the GPS satellites from the CODE reprocessing solution are added (green).

References

Dach, R., E. Brockmann, S. Schaer, G. Beutler, M. Meindl, L. Prange, H. Bock, A. Jäggi, and L. Ostini (2009), GNSS processing at CODE: status report, *Journal of Geodesy*, *83*(3-4), 353–365, doi:10.1007/s00190-008-0281-2.

Ostini, L., R. Dach, M. Meindl, S. Schaer, and U. Hugentober (2009), FODITS: A New Tool of the Bernese GPS Software, in *Proceedings of the EUREF Symposium 2008*.

Steigenberger, P., M. Rothacher, R. Dietrich, M. Fritsche, A. Rülke, and S. Vey (2006), Reprocessing of a global GPS network, *Journal of Geophysical Research*, *111*, B05402, doi:10.1029/2005JB003747.

Steigenberger, P., M. Rothacher, M. Fritsche, A. Rülke, and R. Dietrich (2009), Quality of reprocessed GPS satellite orbits, *Journal of Geodesy*, *83*(3-4), 241–248, doi:10.1007/s00190-008-0228-7.